SIMULATION OF GRID CONNECTED MODIFIED 9 LEVEL CASCADED

H-BRIDGE MULTILEVEL INVERTER WITH REDUCED SWITCHES

FOR SOLAR POWER APPLICATION

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ABSTRACT

Renewable energy sources plays a key role in recent times as they are free from pollution, unlimited and reduces the cost related with its control. Among them Solar energy is more beneficial as the impact of solar systems on environment are significantly lower than non-solar system. Generally, solar cell is the device which converts solar energy into DC electricity. Usually we need a suitable converter for the purpose of conversion from DC to AC and then it is injected to power Grid. In this paper, the inverter action is carried out by using nine level cascaded H-Bridge inverter with reduced number of switches. The proposed inverter is been used to integrate the solar system to Grid, taking into consideration of Grid requirements. In the absence of solar supply, we use Grid to feed the load. Nine level proposed Multi Level Inverter (MLI) is simulated using MATLAB/Simulink environment and the proposed results are shown in this paper.

KEYWORDS: DC to AC, Solar System to Grid, Nine Level Proposed Multi Level Inverter and MATLAB

I. INTRODUCTION

The Sun is a very large resource of perennial source of energy, hence this energy consumption can meet the present and future requirements on continues basis. So, this attracts attention in the world. The energy from sun i.e., Solar energy is converted to usable electricity. Solar power uses photovoltaic (PV) cells for the conversion of sunlight into electricity. The output from solar cell is in form of Direct current (DC).This DC supply is further used. Then the solar panel is connected to Maximum Power Point Tracking (MPPT).

MPPT is used for pulling out maximum available power from PV module under custom conditions. The obtained maximum power is then given to inverter as input further Inverter converts this DC supply to AC. For high power loads to provide accurate result AC & MLIs are used. The MLI was introduced in 1975 as alternative for high power and medium voltages. The conventional MLIs such as Diode Clamped MLIs which needs extra diodes for combination with switches, whereas the Flying capacitor MLIs need extra Capacitors and it is even difficult to control as the levels increases. Therefore, Cascaded H-bridge MLI (CHBMLI) need separate dc sources which makes it difficult to use.

This paper proposes a latest MLI which is used to convert DC to AC using reduced number of switches, when compared to conventional MLI. By this less number of switches, switching losses can be avoided. The switches used in

this project are MOSFET's as MOSFET's switching time is less, loss associated with it is also less. So, for high frequency applications, where the switching loss plays a major in total power loss of the circuit, this device is the right choice.

The converted AC from proposed MLI is connected to Load. This study illustrates the development of a three phase modified H-Bridge Nine-level inverter with 8 switches. The overall block model is shown in the figure1.1.
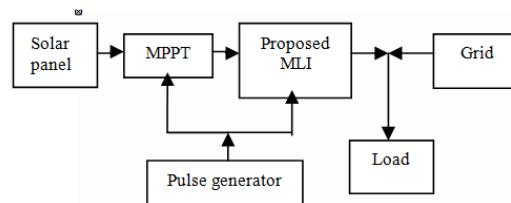

Figure 1.1: Block Diagram of Solar System with Grid Connected to Load

In this paper, the designed solar inverter system is connected to the existing conventional power grid. So that in the absence of solar power the grid supplies power to the load. Due to the connection of solar system to existing power system generates associate power quality problems such as transients, harmonics, voltage fluctuations etc. These problems are mainly due to irradiation, shading effects or cover of cloud makes the solar system unstable in case of grid connection which is discussed in [2]. This paper reduces these problems by integrating capacitive filter devices. Which are placed between the supply and the consumer appliances hence, this will reduce power quality problems by generating or absorbing harmonic power by the load.

The projected MLI topology can overcome some of the limitations when evaluated to the standard 2 level inverter. Harmonics decreases as the number of levels in output voltage increases. Here a 9 level MLI is used so that lower order harmonics are eliminated. Total harmonic distortion (THD) of the output voltage at load is calculated and is also less compared to conventional MLI, thus the power efficiency is fairly more for higher level MLI.

The paper is organized as follows: Section 2 explains about solar system with PV array and MPPT. Section 3 explains multilevel inverter with cascaded H Bridge MLI and proposed multilevel topology. Section 4 shows the simulated results with graphs. Section 5, conclusions are drawn.

II. SOLAR SYSTEM

Most of the energy demands in India (and elsewhere also) can be supplied by simple solar systems. However, one of the fastest developing renewable energy sources in the last few years is photovoltaic (PV) grid-connected systems [10]. Due to the fall in the cost of PV modules (among other factors); grid interlinked photovoltaic power plants are been continually increasing [6]. In power rating mostly now, hundreds of bulky PV based power plants more than 10 MW [7], are working, and even more are under development. Solar energy is converted into electrical energy in PV systems by PV modules.

PV Array

Individual PV cells are interconnected in series which forms a PV module. Solar PV system is formed by many thin films of PV modules this creates the Solar panel for installation. The principle of operation of the PV cell was discovered by Becquerel in 1839 later, Ohl discovered the PV effect at p-n junction of two semiconductors in 1941.

Solar Cell is a p-n semiconductor material made of silicon, when photons of light energy from sun fall on the cell a part of them will be reflected back. The non reflected photons incident on the surface of the cell enter the thin outer layer

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of the semiconductor and are either converted into heat or produce ion-pair by stripping the valance electrons from the semiconductor atoms. Ion-pairs are produced when the incoming energy is in excess of excitation energy. Some carriers escape the electric field of the junction and contribute to decrease electric field at the junction and this in-turn decrease the flow of the majority carriers producing the current flow, DC current is generated [4]. The equivalent solar cell is shown in the below figure2.1.
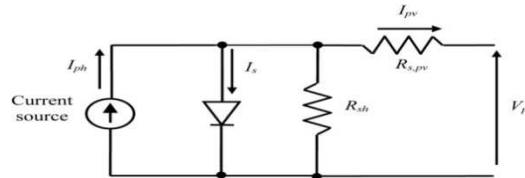

Figure 2.1: The Equivalent Circuit Diagram of Solar Cell

The following equations explain current-voltage characteristics of PV cell:

- PV cell output currentI_{pv}:

- $I_{pv} = I_{ph} - I_s - I_{sh}$

- $I_{pv} = I_{ph} - I_s * \left[e^{\left(\frac{V + I*R_S}{N*V_t} \right)} - 1 \right] - \left(\frac{V + I*R_S}{R_{sh}} \right)$

    Where I_{ph} is Solar Induced current given by

- $I_{ph} = I_{ph0} * \frac{I_r}{I_{r0}}$

- V_t is the thermal voltage, kT/q

- k is the Boltzmann constant.

- T is the Device simulation temperature parameter value.

- q is the elementary charge on an electron.

- N is the quality factor (diode emission coefficient) of the first diode.

- I_s is the saturation current of the diode.

- I_{sh} is the current through parallel resistance

- V is the voltage across the solar cell electrical ports.

- R_s Series resistance.

- R_p Parallel resistor.

This paper presents solar panel of 36 Solar cells connected in series. This gives an open-circuit voltage of about 21V under standard test conditions. The P-V and V-I characteristics are show in below figure 2.2.
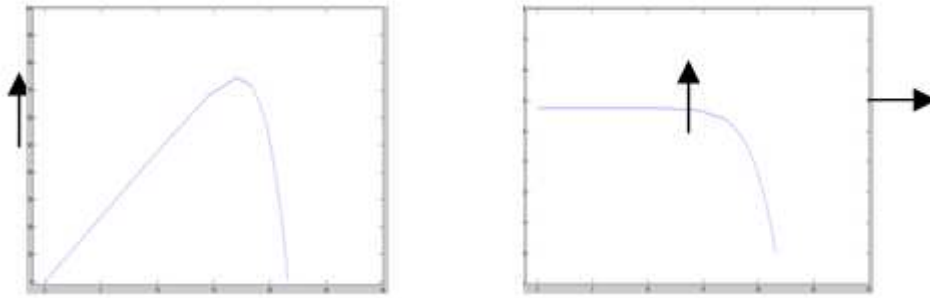
Figure 2.2: P-V and V-I Characteristics of Solar Panel

The actual DC energy from the solar array = (The derivate output power of the module) x (number of modules) x (irradiation for the tilt and azimuth angle of the array).

Solar irradiance is a measure of the irradiance (power per unit area on the Earth's surface) produced by the Sun in the form of electromagnetic radiation, which is taken by humans as sunlight. As the temperature goes on increasing that leads to decrease in voltage and power and by increase in sun irradiation the current, voltage and power values will increase.The output from solar panel is low so there is a need to improve the voltage. Hence, solar panel is connected to the dc-dc power converter, and this converter is a boost converter [3].

MPPT

The maximum power can be extracted from solar panel when the load resistance is equal to the solar cell internal resistance. So if we can vary the resistance maximum power can be drown. As PV module is connected directly to load, the operating point will be at the common point of the load line and V-I curve. As a result load impedance orders system operating condition. Normally, the operating point does not frequently appear same at solar module Maximum power point (MPP), so there is no maximum point. To keep away from this problem, a maximum power point track is placed to maintain operating point. A MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the Inverter. The boost converter performs the MPPT of the generator solar side. The impedance matching of solar module and the load to obtain maximum power can be modeled by Boost network. The DC-DC Boost circuit is shown in below figure 2.3. The boost converter is composed of inductor L, capacitor C, Power electronic switch S and a diode D.
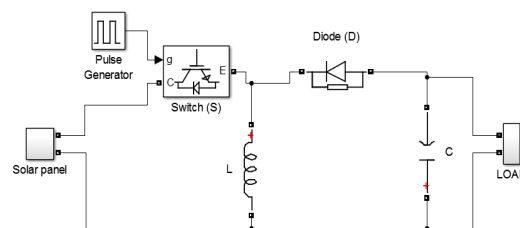

Figure 2.3: DC-DC Boost converter

By varying the pulse width of the gate signal of the switch S the impedance seen by the solar panel will also vary thus solar panel will be able to supply maximum power. If the pulse width is less than 50 converter acts as buck network, otherwise boost network. Here in this paper we use only boost to increase the output of solar panel.

When switch S is turned ON the current flows through the inductor L, L stores the energy. During this, diode D is blocked. When switch S is turned OFF, inductor L will supply energy both to the load and the capacitor C. The stored

energy in capacitor will supply energy to load when switch S is turned ON. In this way the maximum power is been delivered to the load. The solar panel connected to MPPT module forms a solar system. In this paper the designed solar system is connected as DC supply input to the Inverter.

III. MULTILEVEL INVERTER

Cascaded H-Bridge MLI

Most of An Inverter converts a fixed dc voltage to an ac voltage of variable frequency and of fixed or variable magnitude. Inverters are designed using by using semiconductor devices like power transistors, MOSFETs, IGBTs, GTOs and thyristor etc.

Now a day's many industrial applications are requiring high power input. The multi level inverter has been introduced in 1975 for high power and medium voltages. MLIs comprise semiconductors, voltage sources, capacitors generate voltages of stepped waveforms. MLIs have numerous advantages when compared with two level converters. MLI generates output stepped voltages with less dv/dt stress and little distortion. These can manage system dynamic behavior, decrease the power quality problems. Using MLI renewable energy sources can be interfaced to the grid, using several low voltage DC sources like solar energy. Multilevel inverter formats types are mainly of three types which are Diode clamped multilevel inverter, flying capacitors multilevel inverter, Cascaded H- bridge multilevel inverter. Among these topologies, the most accepted inverter is cascaded H-bridge MLI [5]. It exhibits most attractive features as no capacitor voltage problems, simple circuit, less components. The series connection of multiple H-bridge inverters forms to Cascaded H-bridge MLI. Each H-bridge has similar configuration as a typical full bridge inverter of single phase. Cascaded H-bridge MLI uses separate DC source, each H-bridge inverter is connected to its own DC source. Depending on the number of voltage levels H-bridges are connected in series with individual DC sources. The number of output voltage levels is given by:

$$V = 2n+1$$

Where V is the number of voltage levels and n is the number of separate DC sources [12]. For a possible number of levels in output voltage is more than the double number of DC sources. The solar power conversion is the finest suitable applications for cascaded H-bridge MLI, as each inverter require separate DC source.

The main disadvantage of cascaded H-bridge MLI is that it increases number of power semiconductor switches by which complication in gate driver circuit, switching losses also increases. These complications can be reduced by minimizing the reliability of the inverter [13]. It can be solved effectively by reducing the number of switches for same levels of voltages. The required number of voltage levels to the number of switches is important element. For a more number of voltage levels without addition of number of bridges, a new topology of reduced switches for application of solar system is designed in this paper.

Proposed Multilevel Inverter Topology

The main objective is to improve the MLI voltage output quality with less number of switches [1]. A key issue in MLI design is generating sinusoidal voltage waveform. A major concern in switching technique is finding out the switching angles to produce the fundamental frequency. This paper presents an appropriate topology for MLI with fewer switches which suites for renewable energy (solar) source interface.

The general structure of the proposed MLI circuit is shown in the figure 3.1. The switches are positioned in the manner as shown below due to which cost and the overall weight of MLI decreases. This circuit need just eight switches for single phase nine level inverter and twenty four switches for three phase nine level inverter. For this topology, we just need to insert only one switch for every increase in level.
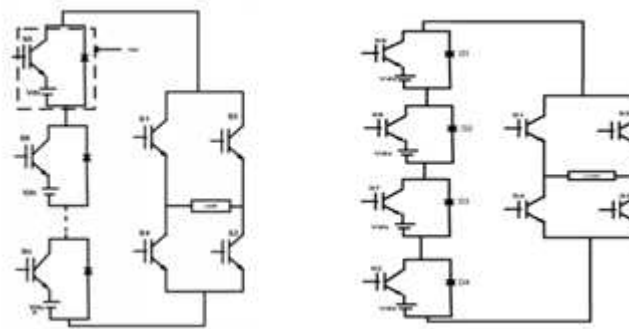

Figure 3.1: General Structure of the proposed MLI Circuit

Each DC source is replaced with solar system. By turning ON switches S_1, S_2 generates $+V_{dc}$, for $-V_{dc}$ turn ON switches S_3,S_4. Nine level voltage is obtained by proper gating pulse of inverter switches ($+4V_{dc}$,$+3 V_{dc}$,$+2 V_{dc}$,$+ V_{dc}$,0,$-V_{dc}$,$-2 V_{dc}$,$-3 V_{dc}$,$-4 V_{dc}$)

The proposed nine level MLI uses 8 switches,4 diodes and 4 DC sources, this paper replaces DC sources shown in figure6. MOSFETs are used as switches. Table I shows the switching sequence of proposed Nine level inverter.

Switching Sequence of Proposed Nine Level MLI

Load Voltage	S1	S2	S3	S4	S5	S6	S7	S8
$+4V_{dc}$	ON	ON	OFF	OFF	ON	ON	ON	ON
$+3 V_{dc}$	ON	ON	OFF	OFF	ON	ON	ON	OFF
$+2 V_{dc}$	ON	ON	OFF	OFF	ON	ON	OFF	OFF
$+ V_{dc}$	ON	ON	OFF	OFF	ON	OFF	OFF	OFF
0	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF
$- V_{dc}$	OFF	OFF	ON	ON	ON	OFF	OFF	OFF
$-2 V_{dc}$	OFF	OFF	ON	ON	ON	ON	OFF	OFF
$-3 V_{dc}$	OFF	OFF	ON	ON	ON	ON	ON	OFF
$-4 V_{dc}$	OFF	OFF	ON	ON	ON	ON	ON	ON

The output waveform of ideal nine level proposed MLI is shown in below fig3.2 with voltages:

- $0V_{dc}, \pm Vdc, \pm 2Vdc, \pm 3Vdc, \pm 4Vdc$

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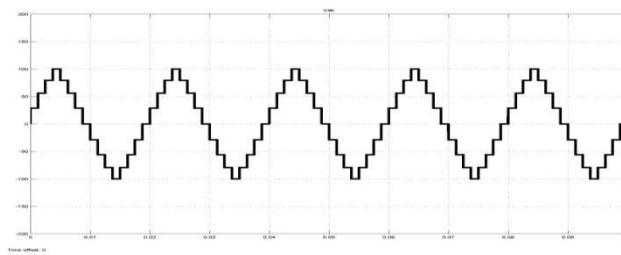with Reduced Switches for Solar Power Application

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Figure 3.2: Nine Level Load Voltage of Proposed MLI

By switching the MOSFETs firing angle, we obtain the desired nine level output voltage, fast switching is done by MOSFETs.

IV. SIMULATION RESULTS

Simulation results for the proposed solar connected nine level inverter which is integrated to the grid using MATLAB/Simulink. This project consists of solar panel of 36 solar cells connected in series, with irradiance of 1000 W/m^2, produced a DC voltage of 21V. As the output from solar panel is insufficient to connect the inverter, the panel output is to be boosted; the DC-DC boost converter is used, produced voltage of 160V shown in fig4.1. Due to the changes in solar radiation, fast switching there effects the output voltage of the boost converter. To reduce the effect capacitors are placed in parallel.
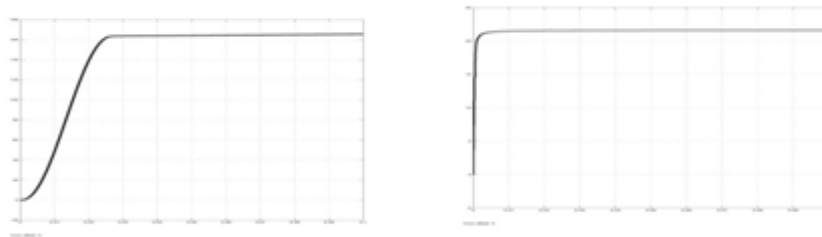

Figure 4.1: Output Voltage Waveforms. (a) Solar Panel. (b) Boost Converter

The DC supply from solar system is connected as input to the proposed MLI to convert DC to AC, MATLAB simulated circuit is shown in the Table. MOSFETs are used as switches, as switching frequency is high. With proper firing the gate signals to the switches nine level voltage is obtained. The gating signal is as shown in below Table II.

Pulse Generator Values of Switches

Switches	Period (secs)	Pulse Width (% of period)	Phase delay (secs)
S1	0.02	50	0
S2	0.02	50	0
S3	0.02	50	0.01
S4	0.02	50	0.01
S5	0.01	87.5	0
S6	0.01	62.5	0.00125
S7	0.01	37.5	0.0025
S8	0.01	12.5	0.00375

Similar to the proposed single phase MLI circuit, three phase MLI circuit is designed. The figure 4.2 shows the three phase output load voltage waveforms of solar interfaced proposed MLI. Proposed inverter produces an accurate nine levels stepped sinusoidal voltage waveform. Thus, the proposed solar based MLI is successfully simulated.
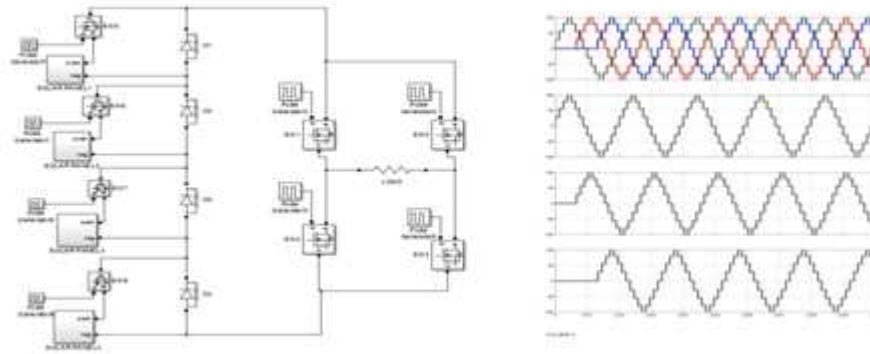

Figure 4.2: Simulation of PV Based Single Phase Proposed Nine Level Inverter and Three Phase Nine Level Voltage Waveforms of Proposed MLI

The generated AC voltage is then connected to a resistive load. In the absence of solar radiation, system is not able to supply the load (consumers). To overcome this problem this paper interconnects the PV based proposed MLI system to the Grid, figure 4.3 shows it in the form of MATLAB simulation. The AC grid supplies energy to the load in the absence of solar energy.
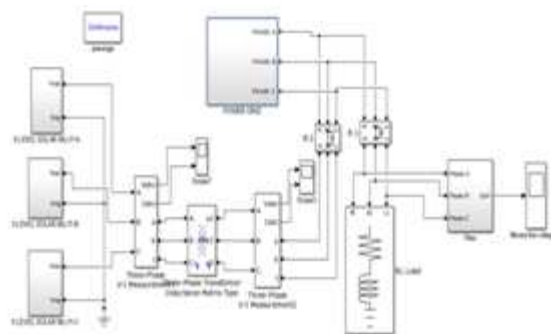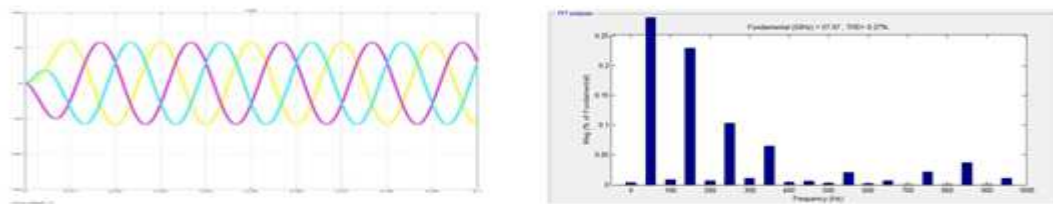

Figure 4.3: Simulation Model of Grid Connected Proposed Nine Level Inverter with the Application of Solar System

Interfacing grid to the solar MLI system produces distortions at the load. This problem is solved by connecting an LP filter at the load end. The figure 4.4(a) shows the simulated output waveform at the load of interfaced solar and grid system and it is clearly observed that a continuous and reduced harmonic wave is achieved.

The line spectrum of the output voltage waveform is taken into account to determine the Total harmonic distortion present in the waveform. Figure 4.4(b) shows the total harmonic distortion as 0.27% for the output voltage of proposed nine level inverter with both resistive and inductive load, which is very less compared to normal Cascaded H-Bridge Inverter [8],[11].

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Figure 4.4 (a) Output of Load Voltage when Solar and Grid System are Connected

(b) 12 FFT Analysis of Output Voltage Waveform of Nine Level MLI with RL Load

V. CONCLUSIONS

A PV based modified MLI of nine level with reduced switches, integrated scheme for power grid is proposed in this paper. This topology eliminates the harmonics at the solar system by expanding and increasing the number of output levels with less number of switches, the initial cost is also reduced. This MLI presents nearly sinusoidal output voltage with very low (0.27%) harmonic content. Simulation results are presented to validate the efficiency of the proposed scheme.

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